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Progress and problems in micro-grid protection schemes

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ABSTRACT

Globally, gradual depletion of fossil fuel resources, poor energy efficiency and environmental pollution are among the main problems faced in the conventional power system. This leads to a new trend of generating power locally by using Distributed Energy Resources (DERs) at distribution voltage level. The concept of micro-grid has appeared as an attractive alternative for integration of DERs in the distribution networks which has numerous advantages in terms of reliability and power quality. Despite the advantages, several challenges are still hindering the development of micro-grids. One of the challenges is micro-grid protection, and to resolve this, researchers have been working to develop different protection schemes. The objective of this study is to review previous research works on the existing protection strategies deployed in addressing micro-grid protection issues in both grid-connected and islanded mode of operation.

Contents

1. Introduction

In order to distribute level energy supply, micro-grid is a method that can be employed where it integrates small-scale DERs into LV as well as MV distribution networks [1–3]. This method generates electricity and heat simultaneously to supply locally for the electrical and heat loads of the customers. The conventional separate stand-alone DER units connected to the existing distribution network in fit-and-forget strategy have substantial dynamic impacts on the main utility grid behavior. In contrast, if they are integrated as micro-grids (with intelligent controllers), the overall distribution system stability and safety can be enhanced. Micro-grids can operate in synchronism with the main grid independently as autonomous islands [4–10]. Normally, they are connected to the main utility grid but still have the

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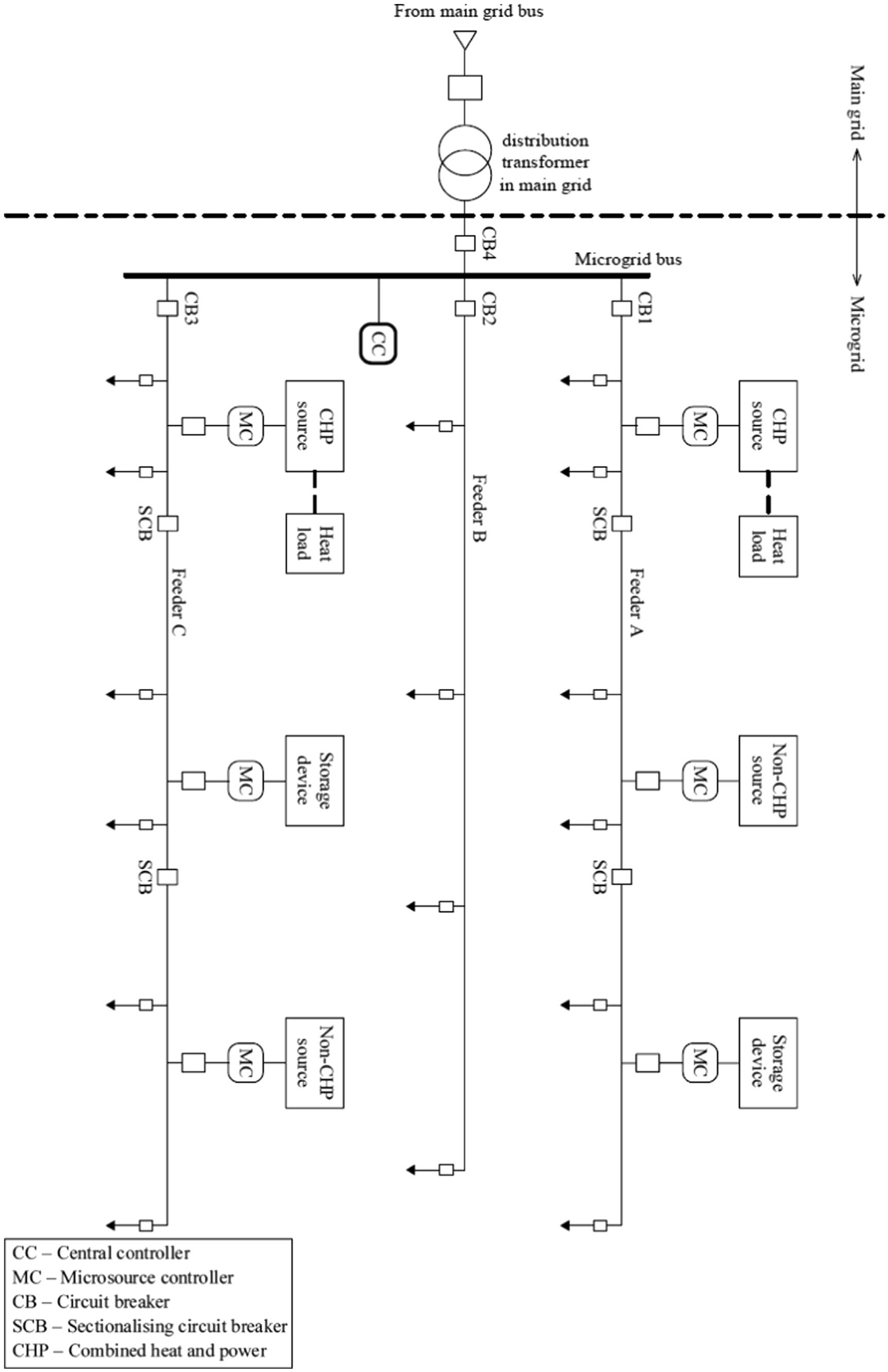

Fig. 1. The configuration of a typical micro-grid.

capability to isolate themselves from the latter if there exists a disturbance in the main grid. This gives the customers an economic and stable performance.

Fig. 1 shows a typical micro-grid configuration. As shown in the figure, a micro-grid is an autonomous group consisting of controllable plug-and play micro-sources and energy storage devices

optimally placed and operated in a manner that is beneficial to the customers [11]. Basically, the micro-sources are renewable/non-conventional DERs driven by a diverse set of controllable prime movers. In order to enable flexible operation of the micro-sources, storage devices are incorporated through the demand side management using their own Micro-source Controllers (MCs). Power electronic-based MC controllers execute necessary local controls of the micro-sources and energy storage devices and this is helpful in maintaining the energy balance and power quality in the system.

The micro-grid presents itself as a single controlled unit of electric and heat loads with local generation to the main utility grid, which is a prominent feature for a stable performance [12–14]. The required flexibility, security and reliability of operation between micro-sources and surrounding AC distribution system are provided by an advanced Power Electronic Interface (PEI) that would bring satisfaction to the customers. Other features of micro-grid that would benefit the main-grid are its capability to decrease congestion, alleviate the immediate needs for generation augmentation, increase system stability, respond to rapid changes in loads and maintain quality of supply to the customers [15–18]. Micro-grids can potentially provide numerous benefits to the main power utility as they are actually active LV and MV networks, which enable them to increase their efficiency of operation and improve reliability and quality of service to satisfy the customers. Nevertheless, various technical and regulatory issues are yet to be carefully addressed which require a considerable amount of research work across the world [19–21]. One of the issues investigated is micro-grid and its entities and various protection schemes have been proposed in the last decades to protect micro-grids against different kinds of faults.

This paper will provide a complete review of the schemes presently applied to address micro-grid protection issues in both islanded and grid-connected operating modes.

2. Micro-grid protection challenges

Majority of distribution systems are operated in a radial mode, where most of them are radially connected. Others may have loop closing feeders, but normally open switches keep the loops open which close only when other parts of the loops are opened due to faults [22,23]. This preserves the radial structure and the system's protective devices are designed for radial operation. Conversely, power flow within the micro-grids can be bidirectional because of the DG connections at different locations. Consequently, the conventional protective devices would be ineffective in protecting the micro-grids.

Another difficulty is associated with the low fault current capacity of the inverter units inside the micro-grid. The capacity is normally less than 50% of the rated current except in cases where they are specifically designed to provide a high fault current [24]. In this circumstance, the fault current available from the micro-sources is reduced compared to the utility generators. The transition from grid-connected to stand-alone operation would result in a marked reduction in micro-grid fault level only if a significant number of micro-sources possess power electronic inverter interfaces. Consequently, the sensitivity and operation of the over-current relays in the system will also be affected. In cases where the relays are set for higher fault currents in a grid-connected operation, the same relays would operate very slowly for the stand-alone operation or may not operate at all due to lower fault currents.

Hence, to protect the micro-grids in both grid-connected and islanded modes of operation, some alternative strategies should be developed because the conventional protective devices will no longer be adequate.

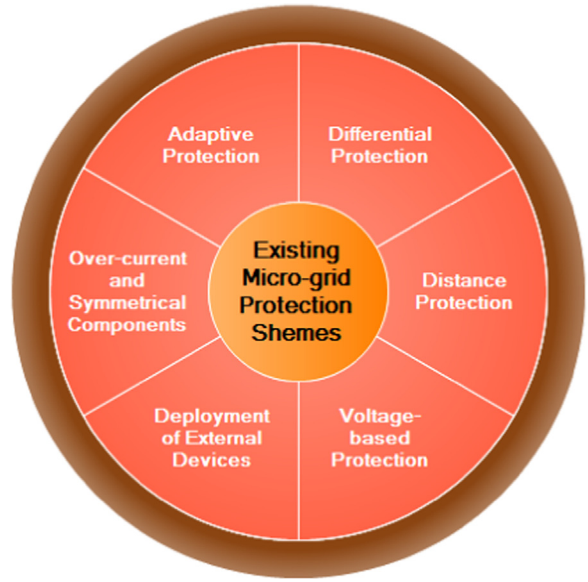

Fig. 2. Existing micro-grid protection schemes.

3. Existing micro-grid protection schemes

In a micro-grid, the operating philosophy is that under normal condition, the micro-grid would operate in the grid-connected mode. However, it would seamlessly disconnect from the utility at the Point of Common Coupling (PCC) and continue to operate as an island if there is a disturbance in the utility [25]. Therefore, a suitable scheme to protect the micro-grid should be able to respond to both utility grid and micro-grid fault incidents.

Over the last few years, numerous schemes for the protection of micro-grids have been devised and reported as shown in Fig. 2. The schemes will be described comprehensively in the following subsections.

3.1. Adaptive protection schemes and their problems

Adaptive protection scheme could solve problems arising from both modes of grid connected and islanded operation. In this protection scheme, automatic readjustment of relay settings would trigger when the micro-grid changes from the grid connected mode to the islanded mode or vice versa. It is an online system that could modify the preferred protective response to change under system conditions or requirements in a timely manner through external generated signals or control actions. Numerical directional over current relays is used to generate the technical requirements and suggestions for practical implementation of an adaptive protection system. Numerical directional over current relays should make possible the use of tripping characteristics (several settings groups) that can be parameterized locally or remotely.

Tumilty et al. [26] had suggested an adaptive protection strategy without the requirement of a communication system. They had employed a voltage based fault detection method in discriminating the voltage drop in short-circuit incidents and overload events. After a few years, Oudalov and Fidigatti [27] proposed another protection scheme aiming to be able to adjust the setting of the relays according to the micro-grid's current state based on offline analysis and online operation. A year later, Han et al. [28] had introduced components for voltage and current fault at the point of installation of the protection to determine the system impedance. Then, it has been discovered that the settings of the current instantaneous protection could be adjusted automatically

by comparing with the utility grid and micro-grid impedances. Dang et al. [29] used Energy Storage (ES) and isolation transformers to recognize the mode of operation of micro-grid. Therefore, identification of the fault could be executed by comparing between the zero sequence current and a threshold value. A few years later, Ustun et al. [1] proposed a scheme called additional adaptive protective scheme which employs extensive communication to monitor and update the relay settings according to the different micro-grid's operation modes. In this scheme, a Central Protection Unit (CPU) is installed to the micro-grid and the protection unit communicates with the relays and DGs to update their operating currents and to store their status as ON/OFF respectively. Khederzadeh [30] on the other hand, has suggested a methodology to coordinate the over-current relays within a certain micro-grid. In this methodology, the relay settings were adjusted to be suitable to the status of micro-grid based on their different operating modes.

The main issues related with the implementation of adaptive protection strategies mentioned above are as listed below:

– Updating or upgrading of the protection devices which are currently employed in the power networks is required.
– All possible configurations of micro-grid need to be known before implementing these schemes.
– Establishment of a communication infrastructure may involve high cost.
– Calculation of short-circuit will be difficult for a micro-grid with different operating modes.

3.2. *Differential protection schemes and their problems*

Differential protection compares the currents that enter and leave a protected zone and will only operate when the differential between these currents exceeds a pre-determined magnitude. There are a number of research works that have used differential protection to provide an adequate protection system. Nikkhajoei and Lasseter [31] proposed a combined technique for micro-grid protection by differential protection and symmetrical components calculations. They used zero sequence and negative sequence currents within the micro-grid to detect Single Line-to-Ground (SLG) and Line-to-Line (LL) Faults, respectively. Zeineldin et al. [32] discussed the micro-grids future and were concerned on two major challenges, voltage/frequency control and protection. Consequently, they developed a strategy where they had made use of differential relays in both ends of each line. These relays which are designed to operate in 50 ms were capable of protecting the micro-grid in both grid-connected and autonomous operation modes. Then, Conti et al. [33] detailed out three protection strategies in detection phase-to-ground faults in isolated neutral micro-grids. In addition, they had also presented three more protection schemes for three-phase faults in micro-grids with synchronous based generators. A year later, Sortomme et al. [34] proposed a novel protection scheme based on some principles of synchronized phasor measurements and microprocessor relays in order to recognize all kinds of faults including High Impedance Faults (HIFs). They had found that installing the relays at the end of each micro-grid line will provide a robust protection. Parsai et al. [35] introduced a communication-based methodology called Power Line Carrier (PLC) with multiple levels of protection to offer the most effective kind of network protection for meshed micro-grids. Recently, a novel methodology was put forward by Dewadasa et al. [36] in 2011, which is also based on differential protection. This methodology takes into account all the protection challenges such as bidirectional power flow and reduction of fault current level in the islanded operation mode and it is capable of protecting the micro-grids in both grid-connected and islanded modes of operation. One of the outstanding features of this method is not only the feeder protection but also the protection of buses and DG sources within the micro-grid.

One of the most substantial benefits gathered from implementation of the differential protection approaches is that they are not sensitive to bidirectional power flow and fault current level reduction in islanded micro-grids. However, there are some associated challenges which can be summarized as follows:

– As there is a possibility that the communication system may fail, it is necessary to provide a secondary protection scheme.
– Establishment of a communication infrastructure is relatively expensive.
– Difficulties may be faced in an unbalanced systems or loads.
– Transients during connection and disconnection of DGs may cause some problems.

3.3. *Distance protection schemes and their problems*

The impedance of a line is proportional to its length, thus it is appropriate to use a relay that can measure the impedance of a line up to a predetermined point (the reach point) for distance measurement. Such a relay is called a distance relay and it is designed to operate only for faults that occur between the location of the relay and the selected reach point.

Dewadasa [37,38] has developed the main strategy in this group. It is based on an admittance relay with characteristics of inverse time tripping. The relay is capable of distinguishing and isolating the faults in both grid-connected and autonomous micro-grids.

Difficulties related with the application of these types of relays are listed below:

– Some problems may be faced in terms of accuracy of extracting fundamentals resulting from its harmonics and transient behavior of current.
– Some errors might be generated by the fault resistance in the measured admittance.
– It is hard to measure the admittance for short lines in the distribution networks.

3.4. *Voltage-based protection schemes and their problems*

Substantially, voltage-based protection techniques employ voltage measurements in protecting the micro-grids against different kinds of faults.

In 2006, Al-Nasseri et al. [39] have proposed one of the most valuable approaches in this field. The proposed scheme that can monitor and transform output voltages of DG sources into dc quantities using the d-q reference frame is capable of protecting the micro-grids against in-zone and out-of-zone faults. In addition, they deployed a communication link deployed in the scheme to discriminate in-zone and out-of-zone faults. Due to the fact that the distances within a micro-grid are usually short, the communications can be established using pilot wires, optical fibers or the Ethernet. Later, a novel protection strategy was proposed by Loix et al. [11] in 2009. This protection strategy is based on the effect of different fault types on Park components of the voltage and it has the ability to protect micro-grids against three phase, two phase and one phase-to-earth faults. The operation of the protection strategy is not governed by the communication system but could be optimized through communication links between different detection modules. The most prominent feature of this scheme

compared to the one proposed by Al-Nasseri et al. [39] is its versatility where it could be used to protect different micro-grids with various configurations. Lastly, an additional protection strategy was then introduced by Wang et al. [40], which is based on busbar voltage analysis and the fault direction to protect micro-grids in both grid-connected and autonomous operation modes. In addition, they had developed the relay protection hardware and software using Industrial Personal Computers (IPCs).

Below is the list of the possible main complications with regard to implementation of voltage-based protection strategies:

– Mis-operation of protection devices can result in any voltage drop within the micro-grid.
– The above-mentioned methodologies cannot identify HIFs.
– Majority of these techniques are designed and tested for certain specific micro-grids. As a matter of fact, they strongly depend on the configuration of the micro-grid and on the protection zone definition. Therefore, they might not be appropriate for micro-grids with different structures.
– The grid-connected mode of operation has less sensitivity.

3.5. Protection schemes with the deployment of external devices and their problems

As stated earlier, the challenge faced in micro-grid protection is associated with the huge difference between the fault current level in the grid-connected mode and the autonomous mode [41]. Hence, it is imperative to implement an adequate protection scheme which is able to operate suitably in both grid-connected and autonomous modes.

Substantially, these protection schemes are based on modification of the short-circuit level when the micro-grid operation mode changes from grid-connected to autonomous, or vice versa. These devices can be classified into the following two groups:

3.5.1. Fault Current Limiters (FCLs)

FCLs can be employed to reduce the aggregated contribution of many distributed generation units, and it is capable of adequately changing the short circuit current level to exceed the design limit of different equipment components.

The main developed FCL protection was developed by Ustan et al. [1] in 2011. Their proposed FCL uses a Central Protection Unit (CPU) together with a communication system to monitor the micro-grid status and update relays' trip value based on the changes in the system.

The most prominent challenge in applying FCL-based protection techniques is in terms of determination of the FCL impedance value, where it is difficult to be determined for micro-grids with widespread proliferation of DGs due to the mutual influence of DGs. Furthermore, the transient response of the FCL should also be of concern.

3.5.2. Energy storage devices

Due to the fact that the short circuit current level in the micro-grid is limited to approximately 2–3 times of the rated current because of the existence of inverter-based DGs, energy storage devices can be used to provide supplementary short-circuit level to the network such as flywheels and batteries [1,42].

Below is the list of some difficulties related to the use of strategies based on additional current source:

– Storage devices will involve significant investments.
– These strategies depend on the technology of the islanding detection and storage devices' convenient operation.

3.6. Protection schemes based on over-current and symmetrical components and their problems

These protection strategies evolved mainly from the current symmetrical components analysis and they attempt to improve the conventional over-current protection performance and provide a robust micro-grid protection system.

One of the most significant approaches was developed by Nikkhajoei and Lasseter [31] in 2006. Their new proposed technique is based on the zero sequence current and negative sequence current measurements to distinguish single Line-to-Ground and Line-to-Line faults, respectively. In 2008, Best et al. [43] built a three-stage selectivity scheme assisted by communication. Their method consists of three stages where stage-one recognizes the fault event according to the local measurements; stage-two deploys inter-breaker communications; and stage-three adapts the relays settings via a supervisory controller. Later, Zamani et al. [44] developed a new protection scheme using micro-processor based relays for low-voltage micro-grids protection against types of faults in both grid-connected and autonomous modes of operation. The significant characteristic of the developed scheme is that all relays within the micro-grid are coordinated in accordance to a definite-time grading method; hence no communication links between the relays is needed.

The main complication of most of the protection strategies mentioned above is regarding the need of communication systems. In such schemes, the coordination of the protection may be endangered if there exists a failure in the communication system.

4. Conclusion

The purpose of micro-grid is to meet the reliability and power quality needed by the customers. Nevertheless, some significant challenges are faced in the emergence of micro-grids and protection of micro-grid and its entity is among them. One major relevant challenge to micro-grid protection is to find an effective protection strategy for both grid-connected and islanded mode of operation. In the past few decades, various strategies have been introduced to provide adequate protection for micro-grids. A robust protection scheme should have the capability to protect the micro-grid against all kinds of faults and provide assured safe and secure operation in both grid-connected and autonomous mode. The aim of the current study was to comprehensively review the existing proposed strategies in tackling the issues regarding micro-grid protection and to categorize them into specific groups.

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